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APPLICATION FOR LETTERS PATENT

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CAPACITOR FABRICATION METHODS AND CAPACITOR CONSTRUCTIONS

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TECHNICAL FIELD

BACKGROUND OF THE INVENTION

Capacitors are common devices used in electronics, such as integrated circuits, and particularly semiconductor-based technologies. Two common capacitor structures include metal-insulator-metal (MIM) capacitors and metal-insulator-semiconductor (MIS) capacitors. One important factor to consider when selecting a capacitor structure may be the capacitance per unit area. MIS capacitors may be advantageous since a first electrode as the semiconductor may be formed of hemispherical grain (HSG) polysilicon that exhibits a higher surface area in a given region compared to a planar surface of amorphous silicon. The higher surface area provides more capacitance per unit area occupied by a capacitor.

However, a high K factor (also known as dielectric constant or “κ”) dielectric material may be desirable to further enhance capacitance. Ta₂O₅ is one example of a high K factor dielectric, but it inherently forms an interfacial dielectric layer of SiO₂ when formed on a capacitor

1 electrode comprising HSG. The interfacial dielectric exhibits a lower K
2 factor than Ta_2O_5 and thus reduces the effective dielectric constant for
3 the capacitor construction. Such reduction may be significant enough to
4 eliminate any gain in capacitance per unit area otherwise achieved by
5 using HSG instead of a planar electrode. Use of other oxygen
6 containing high K dielectric materials has proved to create similar
7 problems.

8 Because it may be desirable to provide area enhancement of an
9 electrode in a MIM structure using HSG, one attempt at addressing the
10 stated problem is forming a silicon nitride insulative barrier layer over
11 the HSG. The silicon nitride barrier layer may be formed by nitridizing
12 the silicon of the outer surface of HSG. Unfortunately, silicon nitride
13 exhibits a K factor of only about 7, less than the K factor of some high
14 K factor dielectrics that are desirable. Accordingly, even the silicon
15 nitride barrier layer reduces the effective dielectric constant of the
16 capacitor.

SUMMARY OF THE INVENTION

In one aspect of the invention, a capacitor fabrication method may include forming a first capacitor electrode over a substrate and atomic layer depositing a conductive barrier layer to oxygen diffusion over the first electrode. A capacitor dielectric layer may be formed over the first electrode and a second capacitor electrode may be formed over the dielectric layer.

Another aspect of the invention may include chemisorbing a layer of a first precursor at least one monolayer thick over the first electrode and chemisorbing a layer of a second precursor at least one monolayer thick on the first precursor layer, a chemisorption product of the first and second precursor layers being comprised by a layer of a conductive barrier material.

Also, in another aspect of the invention a capacitor fabrication method may include forming a first capacitor electrode over a substrate. The first electrode can have an inner surface area per unit area and an outer surface area per unit area that are both greater than an outer surface area per unit area of the substrate. A capacitor dielectric layer may be formed over the first electrode and a second capacitor electrode may be formed over the dielectric layer.

A still further aspect includes a capacitor fabrication method of forming an opening in an insulative layer over a substrate, the opening having sides and a bottom, forming a layer of polysilicon over the sides

1 and bottom of the opening, and removing the polysilicon layer from over
2 the bottom of the opening. At least some of the polysilicon layer may
3 be converted to hemispherical grain polysilicon. A first capacitor
4 electrode may be conformally formed on the converted polysilicon, the
5 first electrode being sufficiently thin that the first electrode has an outer
6 surface area per unit area greater than an outer surface area per unit
7 area of the substrate underlying the first electrode. A capacitor
8 dielectric layer may be formed over the first electrode and a second
9 capacitor electrode may be formed over the dielectric layer.

10 Other aspects of the invention include the capacitor constructions
11 formed from the above described methods.
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13

14 **BRIEF DESCRIPTION OF THE DRAWINGS**

15 Preferred embodiments of the invention are described below with
16 reference to the following accompanying drawings.

17 Fig. 1 is an enlarged view of a section of a semiconductor wafer
18 at one processing step in accordance with the invention.

19 Fig. 2 is an enlarged view of the section of the Fig. 1 wafer at
20 a processing step subsequent to that depicted by Fig. 1.

21 Fig. 3 is an enlarged view of the section of the Fig. 1 wafer at
22 a processing step subsequent to that depicted by Fig. 2.
23

1 Fig. 4 is an enlarged view of the section of the Fig. 1 wafer at
2 a processing step subsequent to that depicted by Fig. 3.

3 Fig. 5 is an enlarged view of the section of the Fig. 1 wafer at
4 a processing step subsequent to that depicted by Fig. 4.

5 Fig. 6 is an enlarged view of the section of the Fig. 1 wafer at
6 a processing step subsequent to that depicted by Fig. 5.

7 Fig. 7 is an enlarged view of the section of the Fig. 1 wafer at
8 an alternate embodiment processing step subsequent to that depicted by
9 Fig. 2 in accordance with alternate aspects of the invention.

10 Fig. 8 is an enlarged view of the section of the Fig. 1 wafer at
11 a processing step subsequent to that depicted by Fig. 7.

12 Fig. 9 is an enlarged view of the section of the Fig. 1 wafer at
13 a processing step subsequent to that depicted by Fig. 8.

14 Fig. 10 is an enlarged view of the section of the Fig. 1 wafer at
15 a processing step subsequent to that depicted by Fig. 9.

16 17 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

18 This disclosure of the invention is submitted in furtherance of the
19 constitutional purposes of the U.S. Patent Laws "to promote the progress
20 of science and useful arts" (Article 1, Section 8).

21 Atomic layer deposition (ALD) involves formation of successive
22 atomic layers on a substrate. Such layers may comprise an epitaxial,
23 polycrystalline, amorphous, etc. material. ALD may also be referred to

1 as atomic layer epitaxy, atomic layer processing, etc. Further, the
2 invention may encompass other deposition methods not traditionally
3 referred to as ALD, for example, chemical vapor deposition (CVD), but
4 nevertheless including the method steps described herein. The deposition
5 methods herein may be described in the context of formation on a
6 semiconductor wafer. However, the invention encompasses deposition on
7 a variety of substrates besides semiconductor substrates.

8 In the context of this document, the term "semiconductor
9 substrate" or "semiconductive substrate" is defined to mean any
10 construction comprising semiconductive material, including, but not limited
11 to, bulk semiconductive materials such as a semiconductive wafer (either
12 alone or in assemblies comprising other materials thereon), and
13 semiconductive material layers (either alone or in assemblies comprising
14 other materials). The term "substrate" refers to any supporting
15 structure, including, but not limited to, the semiconductive substrates
16 described above.

17 Described in summary, ALD includes exposing an initial substrate
18 to a first chemical species to accomplish chemisorption of the species
19 onto the substrate. Theoretically, the chemisorption forms a monolayer
20 that is uniformly one atom or molecule thick on the entire exposed
21 initial substrate. In other words, a saturated monolayer. Practically, as
22 further described below, chemisorption might not occur on all portions
23 of the substrate. Nevertheless, such an imperfect monolayer is still a

1 monolayer in the context of this document. In many applications, merely
2 a substantially saturated monolayer may be suitable. A substantially
3 saturated monolayer is one that will still yield a deposited layer
4 exhibiting the quality and/or properties desired for such layer.

5 The first species is purged from over the substrate and a second
6 chemical species is provided to chemisorb onto the first monolayer of the
7 first species. The second species is then purged and the steps are
8 repeated with exposure of the second species monolayer to the first
9 species. In some cases, the two monolayers may be of the same species.
10 Also, a third species or more may be successively chemisorbed and
11 purged just as described for the first and second species.

12 Purging may involve a variety of techniques including, but not
13 limited to, contacting the substrate and/or monolayer with a carrier gas
14 and/or lowering pressure to below the deposition pressure to reduce the
15 concentration of a species contacting the substrate and/or chemisorbed
16 species. Examples of carrier gases include N₂, Ar, He, Kr, Ne, Xe, etc.
17 Purging may instead include contacting the substrate and/or monolayer
18 with any substance that allows chemisorption byproducts to desorb and
19 reduces the concentration of a contacting species preparatory to
20 introducing another species. A suitable amount of purging can be
21 determined experimentally as known to those skilled in the art. Purging
22 time may be successively reduced to a purge time that yields an increase
23 in film growth rate. The increase in film growth rate might be an

1 indication of a change to a non-ALD process regime and may be used
2 to establish a purge time limit.

3 ALD is often described as a self-limiting process, in that a finite
4 number of sites exist on a substrate to which the first species may form
5 chemical bonds. The second species might only bond to the first species
6 and thus may also be self-limiting. Once all of the finite number of
7 sites on a substrate are bonded with a first species, the first species will
8 often not bond to other of the first species already bonded with the
9 substrate. However, process conditions can be varied in ALD to
10 promote such bonding and render ALD not self-limiting. Accordingly,
11 ALD may also encompass a species forming other than one monolayer
12 at a time by stacking of a species, forming a layer more than one atom
13 or molecule thick. The various aspects of the present invention
14 described herein are applicable to any circumstance where ALD may be
15 desired.

16 Often, traditional ALD occurs within an often-used range of
17 temperature and pressure and according to established purging criteria
18 to achieve the desired formation of an overall ALD layer one monolayer
19 at a time. Even so, ALD conditions can vary greatly depending on the
20 particular precursors, layer composition, deposition equipment, and other
21 factors according to criteria known by those skilled in the art.
22 Maintaining the traditional conditions of temperature, pressure, and
23 purging minimizes unwanted reactions that may impact monolayer

1 formation and quality of the resulting overall ALD layer. Accordingly,
2 operating outside the traditional temperature and pressure ranges may
3 risk formation of defective monolayers.

4 The general technology of chemical vapor deposition (CVD)
5 includes a variety of more specific processes, including, but not limited
6 to, plasma enhanced CVD and others. CVD is commonly used to form
7 non-selectively a complete, deposited material on a substrate. One
8 characteristic of CVD is the simultaneous presence of multiple species
9 in the deposition chamber that react to form the deposited material.
10 Such condition is contrasted with the purging criteria for traditional ALD
11 wherein a substrate is contacted with a single deposition species that
12 chemisorbs to a substrate or previously deposited species. An ALD
13 process regime may provide a simultaneously contacted plurality of
14 species of a type or under conditions such that ALD chemisorption,
15 rather than CVD reaction occurs. Instead of reacting together, the
16 species may chemisorb to a substrate or previously deposited species,
17 providing a surface onto which subsequent species may next chemisorb
18 to form a complete layer of desired material. Under most CVD
19 conditions, deposition occurs largely independent of the composition or
20 surface properties of an underlying substrate. By contrast, chemisorption
21 rate in ALD might be influenced by the composition, crystalline
22 structure, and other properties of a substrate or chemisorbed species.

1 Other process conditions, for example, pressure and temperature, may
2 also influence chemisorption rate.

3 ALD, as well as other deposition methods and/or methods of
4 forming conductive barrier layers may be useful in capacitor fabrication
5 methods. According to one aspect of the invention, a capacitor
6 fabrication method includes forming a first capacitor electrode over a
7 substrate and atomic layer depositing a conductive barrier layer to oxygen
8 diffusion over the first electrode. A capacitor dielectric layer may be
9 formed over the first electrode and a second capacitor electrode may be
10 formed over the dielectric layer. At least one of the first or second
11 capacitor electrodes may comprise polysilicon, preferably hemispherical
12 grain (HSG) polysilicon. The dielectric layer may comprise oxygen.
13 Exemplary materials for the dielectric layer include, but are not limited
14 to, Ta_2O_5 , ZrO_2 , WO_3 , Al_2O_3 , HfO_2 , barium strontium titanate (BST), or
15 strontium titanate (ST).

16 Notably, the conductive barrier layer to oxygen diffusion formed
17 over the first electrode may provide the advantage of reducing oxidation
18 of the electrode by oxygen diffusion from an oxygen source, for example,
19 the dielectric layer. The dielectric layer may be formed over the barrier
20 layer, thus, the barrier layer may reduce oxygen diffusion to the first
21 capacitor electrode. Alternatively, such a barrier layer may reduce
22 oxygen diffusion from the first capacitor electrode or under the first
23 capacitor electrode to the dielectric layer or second capacitor electrode.

1 It follows then that the barrier layer may also be formed over the
2 capacitor dielectric layer with the second capacitor electrode over the
3 barrier layer such that the barrier layer reduces oxygen diffusion from
4 the dielectric layer to the second electrode. Such positioning may also
5 reduce oxygen diffusion from over the dielectric layer to the first
6 capacitor electrode, for example, oxygen diffusion from the second
7 capacitor electrode. Accordingly, one aspect of the invention may
8 include atomic layer depositing the barrier layer over the first electrode,
9 forming the dielectric layer over the barrier layer, and atomic layer
10 depositing another conductive barrier to oxygen diffusion over the
11 dielectric layer.

12 Prior to the atomic layer depositing, it may be advantageous to
13 clean the deposition substrate, for example, the first electrode. Cleaning
14 may be accomplished by a method comprising HF dip, HF vapor clean,
15 or NF_3 remote plasma. Such cleaning methods may be performed in
16 keeping with the knowledge of those skilled in the art. Likewise,
17 forming the first and second electrodes and dielectric layer may be
18 accomplished by methods known to those skilled in the art and may
19 include atomic layer deposition, but preferably other methods.

20 The atomic layer depositing of the barrier layer may occur at a
21 temperature of from about 100 to about 600 °C and at a pressure of
22 from about 0.1 to about 10 Torr. The dielectric layer may exhibit a K
23 factor of greater than about 7 at 20 °C. Examples of suitable materials

1 for the barrier layer include WN, WSiN, TaN, TiN, TiSiN, Pt, Pt alloys,
2 Ir, Ir alloys, Pd, Pd alloys, RuO_x, or IrO_x, as well as other materials.
3 The barrier layer may have a thickness of from about 50 to about 500
4 Angstroms or another thickness depending on the material properties.

5 One consideration in selecting a material for the barrier layer is
6 the thickness and density of the barrier layer that will be sufficient to
7 achieve a desired level of oxygen diffusion reduction. Another factor to
8 evaluate is that the barrier layer might be considered to form a part of
9 a capacitor electrode when the barrier layer contacts one of the first or
10 second electrodes since the barrier layer is conductive. Accordingly, it
11 may be advantageous to recalculate the desired dimensions of an
12 electrode contacted by the barrier layer accounting for the presence of
13 the additional conductive material. Accordingly, a "conductive" material
14 as the term is used herein designates a material exhibiting a conductivity
15 at 20°C of greater than 10⁴ microOhm⁻¹ centimeter⁻¹, or preferably
16 greater than about 10¹² microOhm⁻¹ centimeter⁻¹. Notably, such definition
17 expressly includes "semiconductive" material in the range of about 10⁴
18 to about 10¹² microOhm⁻¹ centimeter⁻¹. As an alternative, a "conductive"
19 material in the present context might be viewed as a material that does
20 not substantially impact the capacitance otherwise achieved without the
21 material. Generally, an "insulative" material might produce a change in
22 capacitance as such a barrier layer.

1 As another aspect of the present invention, a capacitor fabrication
2 method may include forming a first capacitor electrode over a substrate,
3 chemisorbing a layer of a first precursor at least one monolayer thick
4 over the first electrode, and chemisorbing a layer of a second precursor
5 at least one monolayer thick on the first precursor layer. A
6 chemisorption product of the first and second precursor layers may be
7 comprised by a layer of a conductive barrier material. Because the
8 chemisorption product is comprised by the barrier layer, the barrier layer
9 may also include conductive barrier material that is not a chemisorption
10 product of the first and second precursor layers. A capacitor dielectric
11 layer may be formed over the first electrode and a second capacitor
12 electrode may be formed over the dielectric layer. The various positions
13 for the barrier layer discussed above are also applicable to the present
14 aspect of the invention.

15 In forming the chemisorption product of the first and second
16 precursor layers, the first and second precursor layers may each consist
17 essentially of a monolayer. Further, the first and second precursor layers
18 may each comprise substantially saturated monolayers. The extent of
19 saturation might not be complete and yet the barrier layer will
20 nevertheless provide the desired properties. Thus, substantially saturated
21 may be adequate. The first and second precursor may each consist
22 essentially of only one chemical species. However, as described above,
23 precursors may also comprise more than one chemical species.

1 Preferably, the first precursor is different from the second precursor,
2 although for some barrier layers, the first and second precursor will be
3 the same. Examples of pairs of first and second precursors include:
4 WF_6/NH_3 , $\text{TaCl}_5/\text{NH}_3$, $\text{TiCl}_4/\text{NH}_3$, tetrakis(dimethylamido)titanium/ NH_3 ,
5 ruthenium cyclopentadiene/ H_2O , $\text{IrF}_5/\text{H}_2\text{O}$, organometallic Pt/organometallic
6 Pt. It is conceivable that more than one of the preceding pairs may
7 comprise the first and second precursors, but preferably only one of the
8 pairs. Additional alternating first and second precursor layers may be
9 chemisorbed in keeping with the above aspect of the invention to achieve
10 a desired thickness for the barrier layer.

11 Although ALD and/or chemisorbing first and second precursors may
12 be suitable for forming a barrier layer, other methods may also be
13 suitable. Accordingly, a variety of barrier layer forming techniques may
14 be used in combination with techniques to increase electrode surface area
15 to provide enhancement of capacitance per unit area.

16 In another aspect of the invention, a capacitor fabrication method
17 can include forming a first capacitor electrode over a substrate where the
18 first electrode has an inner surface area per unit area and an outer
19 surface area per unit area that are both greater than an outer surface
20 area per unit area of the substrate. One example of obtaining the inner
21 and outer electrode surface areas involves further forming rugged
22 polysilicon over the substrate and forming the first electrode over the
23 rugged polysilicon. The first electrode can also be formed on the

1 rugged polysilicon. The rugged polysilicon can have a surface area per
2 unit area greater than the surface area per unit area of conventionally
3 formed polysilicon that is not converted to rugged polysilicon. A
4 capacitor dielectric layer and a second capacitor electrode may be formed
5 over the first electrode to produce a capacitor construction.

6 The first electrode can comprise TiN, as well as other materials,
7 and may be deposited by ALD, CVD, and perhaps other methods. The
8 rugged polysilicon can be HSG polysilicon and it can also be undoped.
9 Thus, in the present aspect a first electrode may be formed having an
10 outer surface area at least 30% greater the substrate outer surface area.
11 Advantageously, the first electrode need not comprise polysilicon to
12 accomplish the surface area enhancement. Further, it is conceivable that
13 the first electrode can be formed over materials other than rugged
14 polysilicon that provide enhanced surface area compared to the substrate
15 underlying the first electrode.

16 To achieve more preferred first electrode surface area, rugged
17 polysilicon may be formed using a seed density sufficiently small to yield
18 at least some spaced apart grains. Thus, forming subsequent layers of
19 the capacitor does not fill the space between grains so much as to
20 reduce the capacitance enhancement possible with the first electrode of
21 increased surface area. Conventionally, HSG is formed to optimize
22 surface area with very closely positioned grains since a capacitor
23 electrode will consist of the HSG. In the present aspect of the

1 invention, less closely positioned grains may be formed than would
2 provide optimal surface area for rugged or HSG polysilicon since the
3 first electrode can be formed on the polysilicon rather than consist of
4 the polysilicon. The less closely position grains of the invention will
5 provide a greater outer surface area for the first electrode compared to
6 what HSG optimized for surface area would provide to a first electrode
7 formed on optimized HSG. Also, undoped grains of rugged polysilicon
8 may provide the advantage of grain size being smaller than for doped
9 grains such that a smaller capacitor container may be used.

10 Figs. 1-6 exemplify the features of the various aspects of the
11 invention described above, as well as other aspects of the invention. For
12 example, according to another aspect of the invention, Fig. 1 shows
13 wafer portion 1 including a substrate 2 with an insulative layer 4 formed
14 thereon. A capacitor fabrication method may include forming an opening
15 16 in insulative layer 4, the opening 16 having sides and a bottom.
16 Although not shown, the opening may expose an electrical contact in
17 substrate 2 for subsequent electrical linking with a capacitor electrode.
18 Turning to Fig. 2, a layer of polysilicon 6 may be formed over the sides
19 and bottom of the opening. Polysilicon layer 6 may then be removed
20 from over the bottom of opening 16 and converted by low density
21 seeding to an undoped rugged layer 8 comprising HSG polysilicon, as
22 shown in Fig. 3. An anisotropic spacer etch may be used to remove
23 polysilicon, preferably before conversion, from over the bottom of the

1 opening while leaving polysilicon over the sides. Accordingly, no
2 undoped polysilicon will exist between an electrical contact, such as a
3 polysilicon or metal plug, in substrate 2 and a bottom capacitor
4 electrode. If polysilicon is present at the bottom, it may cause high
5 contact resistance or an open between the bottom electrode and the
6 contact.

7 In Fig. 4, a first capacitor electrode 10 may be conformally formed
8 on undoped polysilicon 8. First electrode 10 may be sufficiently thin
9 that it has an outer surface area per unit area greater than an outer
10 surface area per unit area of the portion of substrate 2 underlying first
11 electrode 10. For example, first electrode 10 may have a thickness of
12 from about 50 to about 500 Angstroms, preferably about 200 Angstroms.
13 A capacitor dielectric layer 12 may be formed on first electrode 10 as
14 shown in Fig. 5. Fig. 6 shows excess portions of dielectric layer 12 and
15 a subsequently formed second capacitor electrode layer 14 removed from
16 over insulative layer 4 to produce a capacitor construction.

17 Advantageously, first electrode 10 has an enhanced surface area yet
18 might not produce a SiO_2 interfacial dielectric with an oxygen containing
19 dielectric layer since first electrode 10 may comprise materials other than
20 polysilicon, for example, TiN. Accordingly, the benefits of high K
21 dielectrics, such as Ta_2O_5 , may be maximized while still providing
22 enhanced electrode surface area.
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1 Figs. 7-10 exemplify the features of the various aspects of the
2 invention described above pertaining to barrier layers, as well as other
3 aspects of the invention, according to an alternative process flow. For
4 example, Fig. 7 shows wafer portion 1 of Fig. 2 including a substrate 2
5 with insulative layer 4, opening 16 in insulative layer 4, and polysilicon
6 layer 6 converted to a first capacitor electrode 18 comprising doped HSG
7 polysilicon.

8 In Fig. 8, a conductive barrier layer 20 may be conformally formed
9 on first electrode 18 by, for example, ALD. A capacitor dielectric layer
10 22 may be formed on barrier layer 20. The barrier layer may be
11 sufficiently thick and dense to reduce oxidation of electrode 18 by
12 oxygen diffusion from over the barrier layer. One source of oxygen
13 diffusion may be dielectric layer 22. Fig. 9 shows formation of a second
14 capacitor electrode 24 on dielectric layer 22. Fig. 10 shows excess
15 portions of barrier layer 20, dielectric layer 22, and second electrode
16 layer 24 removed from over insulative layer 4 to form a capacitor
17 construction. As described above, a barrier layer may also be formed
18 over a dielectric layer although not shown in the Figures.

19 In a still further alternative aspect of the invention, barrier layer
20 20 may be removed from over insulative layer 4 prior to forming
21 dielectric layer 22. Chemical mechanical polishing is one example of a
22 suitable removal method for excess portions of barrier layer 20.
23 However, such an alternative is less preferred since the portion of first

1 electrode 18 planar with insulative layer 4 might be exposed during
2 polishing and may contact dielectric layer 22. At the point of contact,
3 an SiO₂ interfacial dielectric may form if first electrode 18 includes
4 silicon and dielectric layer 22 includes oxygen.

5 In compliance with the statute, the invention has been described
6 in language more or less specific as to structural and methodical
7 features. It is to be understood, however, that the invention is not
8 limited to the specific features shown and described, since the means
9 herein disclosed comprise preferred forms of putting the invention into
10 effect. The invention is, therefore, claimed in any of its forms or
11 modifications within the proper scope of the appended claims
12 appropriately interpreted in accordance with the doctrine of equivalents.
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